OTTIMIZZARE LE STRUTTURE IN ACCIAIO PER RIDURRE LE EMISSIONI DI CO_2

WHY OPTIMISED STEEL STRUCTURES WILL HELP REDUCING EMBODIED CARBON

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ABSTRACT

The constant increase in the global population is leading to a severe exploitation of our natural resources, a more rational use of these resources is becoming an unavoidable necessity. Almost everything we use daily is entirely or partially made of/with steel. The use of steel is expected to increase to meet the demographic upsurge and the evolving needs of society. Primary steel making is responsible for high emissions and designers must strive to reduce the embodied carbon of the built environment to stem the climate crisis. Decarbonizing material production not only seems to be the only solution, but it is already underway. This alone may not be enough, as design choices also play an important role, lean, and sustainable design needs to be understood and supported. Design is already evolving from "take, make, use and dispose" to a more reasonable "take, make, use, reuse multiple times and then (eventually) recycle". When viewed this way, steel is not only the most versatile material but also the most reusable and recyclable, it can be recycled indefinitely without losing its mechanical properties. Efficient design, exploiting a holistic approach, specifying low carbon alternatives (already available today) is the only way to impact less. In this framework, this work gives an overview on the decarbonization journey of the steel industry and on what designers can do to build in a more sustainable way.

SOMMARIO

L'incremento esponenziale della popolazione mondiale ha portato ad un irreparabile sfruttamento delle risorse naturali, un uso più razionale sta diventando indispensabile per arginare gli effetti sul pianeta. I materiali, e nello specifico quelli da costrizione, sono in parte responsabili dell'uso di risorse primarie ed emissioni di CO_2. L'acciaio, per esempio, è componente fondamentale di molto di quello che ci circonda, anche se non sempre visibile. L'uso di questo materiale è destinato ad aumentare per soddisfare la domanda e per stare al passo con l'evoluzione tecnologica e sociale. Va riconosciuto che la produzione primaria di acciaio è responsabile di elevate emissioni. Ma in generale, il costruito incide notevolmente sulle emissioni globali di CO_2, questo spiega perché i progettisti sono chiamati ad impegnarsi per ridurre l'impatto del costruito e per arginare la crisi climatica. In questo contesto, la decarbonizzazione della produzione dell'acciaio non solo è un'inevitabile necessità, ma è già in corso. Agire solo sul fronte della produzione non è sufficiente, anche le scelte progettuali giocano un ruolo importante, bisogna ripensare all'approccio progettuale in un'ottica circolare e più sostenibile. La progettazione, e in generale l'approccio al costruito, sta evolvendo da un modello lineare "prendere, produrre, utilizzare e smaltire" a un più ragionevole modello di circolarità: "prendere, produrre, utilizzare, riutilizzare più volte e poi (eventualmente) riciclare". In quest'ottica, l'acciaio non è solo il materiale più versatile, ma anche il più riutilizzabile e riciclabile (riciclato infinite volte senza perdere le proprietà meccaniche). È necessaria una progettazione efficiente di strutture in acciaio, concepire i progetti utilizzando un approccio olistico, progettare pensando al fine vita e specificare alternative a bassa impronta carbonica (ad oggi già disponibili sul mercato). Questo lavoro offre una panoramica sul percorso di decarbonizzazione dell'industria siderurgica e su ciò che i progettisti possono fare per valutare alternative più sostenibili.

1 INTRODUCTION

The global construction industry is the world's largest consumer of raw materials and the built environment accounts for between 25 and 40 percent of total carbon emissions in the world. The sector is also responsible for nearly 40% of raw material use annually and around 39% of the total primary energy use. These shares are expected to grow and consequently the impact of emissions from the production of construction materials will increase [1]. Considering that the world's building stock is expected to double by 2060, this will add 100-200 gigatons of embodied carbon from construction materials, and it will be the equivalent of building a city as big as New York every 34 days until 2060 [2]. The construction industry is only expected to expand, thus providing a significant opportunity to improve its efficiency and transition toward a low-carbon future [2].

In response to these trends and to the growing demand for green, sustainable, and low-carbon constructions, the construction industry is making efforts to address emissions. Consumers of newly constructed buildings and infrastructure increasingly require the industry to meet standards of energy efficiency, green building rating systems (like LEED and BREEAM), responsible resource management, and resilience.

However, the journey towards decarbonization of construction material must speed up to meet requirements such as the target of the Paris Agreements.

Although the steel industry has the stigma of being among the highest-emitting industries (about 7% of global carbon dioxide emissions), the carbon footprint of its manufacturing process has decreased by 37 percent per ton since 1990 [2], and today new low carbon alternatives are cutting emissions faster than before. The circularity of steel, enhanced by the possibility to upcycle, unlike other materials, and its low carbon alternatives have encouraged its use in ambitious projects driven by sustainability and facilitated higher ratings than would otherwise have been possible.

A big disadvantage of this great popularity gained by sustainability topic is the amount of data available today and the chaos caused by contradictory information. It is more and more difficult to understand what can be practically done in design to reduce the emissions of construction in general. Starting from this consideration, this work tries to give a brief and non-exhaustive overview on decarbonization of steel production and to present an easy way to estimate the embodied carbon of structural elements with different materials.

1.2 LCA in construction

Life Cycle Assessment (LCA) is the only scientifically based technique for assessing the potential environmental impacts associated with a product or a service. It is the main operational tool of "Life Cycle Thinking" approach. LCA is an objective method of evaluating and quantifying energy, environmental loads, and potential impacts along the entire life cycle, from the acquisition of raw materials to the end of life ("from the cradle to the grave") and beyond (“cradle to cradle”). The tool can be used at different “scales”: for the single product (steel, cement, etc.), for a solution (steel beam, composite flooring) or for a building, a group of buildings or even a city. Designers can use LCA to choose between alternative solutions, while manufacturers use LCA to define the impact of a product, however, for both it can be a useful tool to optimize and reduce the environmental impacts. Several indicators are used in the assessment, but the current focus is on the Global Warming Potential (GWP), which expresses the contribution to the greenhouse effect from a suite of greenhouse gasses relative to the effect of CO_2, whose reference potential is equal to 1. It is expressed in units of CO_2e, where the "e" stands for equivalent. LCA also breaks down the impacts into stages and modules that represent the magnitude of the impacts throughout the life of a product – see Fig.1. An important aspect of carrying out an LCA is to define the goal and scope, and which boundaries are included in the analysis, for example, the analysis can be “*cradle to gate*”, “*cradle to practical completion*” or “*cradle to cradle”* (i.e., including module D) [3]. These aspects are crucial when different products or structural solutions are compared to select a more sustainable option. If all the stages of the LCA are not included, the comparison could be inconsistent and therefore misleading. It is worth emphasising that conclusions reached on a cradle to gate analysis could be different to those on a cradle to grave or cradle to cradle LCA. At European level, LCA supports for the development of Environmental Labeling schemes, which provide information about a product or service in terms of its overall environmental benefits, such as Type III (EPD- Environmental Product Declaration). Type III environmental declarations (EPD), shown in Fig.2 for low carbon structural steel, quantify the environmental information for the life cycle of a product and represent the most reliable and transparent data to develop an LCA assessment at the scale of the building [4].

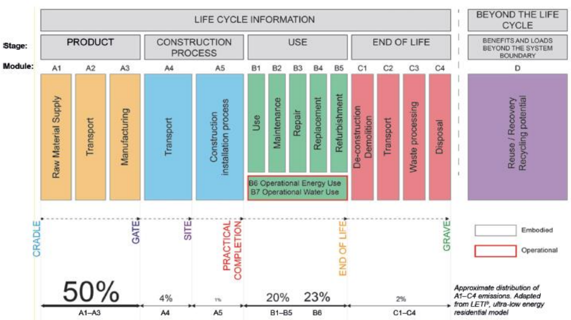


Fig. 1. BS EN 159783 Life cycle stages LCA stages

Fig. 2. EPD XCarb® recycled and renewably produced ArcelorMittal

2 STEEL AND SUSTAINABILITY

To reduce building emissions, three strategies need to be combined:

1. reducing energy demand (individual behaviour and energy efficiency)
2. decarbonization of the energy supply
3. reducing carbon in building materials [1].

The first two are closely linked to the decarbonisation of the energy grid, and it is expected that increasingly effective policies and solutions will be implemented by 2050. The third strategy is of fundamental importance and envisages wider synergies between producers, supply chains and designers. As stated, steel is a key material for technological evolution and in the circular economy. Many advances are currently taking place in the steel industry, increasing the rate of recycling (and potential reuse), implementation of decarbonization strategies [8], industry standards and certification programs (such as ResponsibleSteel), improved productivity and efficiency of process (from energy efficiency to increased use of scrap).

Steel recycling is a well-established and efficient practice with capture rates as high as 99% at end of life(**Fig.3)**. Steel production from scrap is already a mature steelmaking process. However, the predicted increase in global steel demand, means a transition to steelmaking entirely based on scrap will not be possible for some time and so there will still be a need for primary steelmaking, and an urgent need to decarbonise the primary production too.

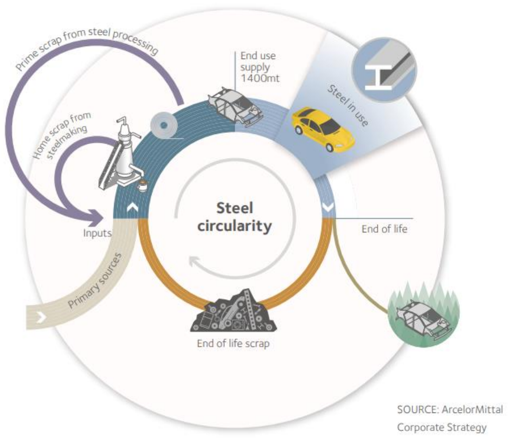


Fig. 3. Steel circularity from [8].

If manufacturers are engaged in the decarbonization process to reduce the carbon footprint of production, designers have an important role to play in the transition. It is no longer enough to simply design efficiently, it is also necessary for designers to understand and engage with the supply chain and be aware of the latest developments and the available alternatives with lower embodied carbon, if they are to successfully deliver low impact buildings.

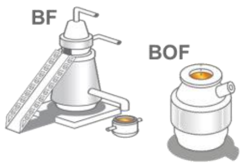
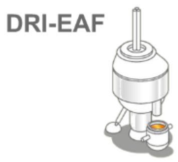
2.1 Steel making routes and emissions

There are currently three main technologies to produce steel:

- BF-BOF (Blast Furnace-Basic Oxygen Furnace) steelmaking.
- Scrap based EAF (Electric Arc Furnace) production and
- DRI-EAF (Direct Reduced Iron followed by an EAF).

In BF-BOF steelmaking, as a first step, primary materials (iron ore and coke) are used to make iron. Carbon, in the form of coke, is used as a reductant to win the iron from the ore resulting in direct carbon dioxide emissions from the chemical reaction (
Table **1**).
Once iron is produced, primary steel can be made either in a Basic Oxygen Furnace (BOF), or in an Electric Arc Furnace (EAF). In the BOF, steel is made by injecting oxygen into the liquid BF iron to remove excess carbon. Scrap steel is used as a coolant, the percentage varying from plant to plant, but typically 10 to 15%, with a technical maximum of around 30% (
Table **1**).
When steel is produced entirely from melting recycled scrap in an EAF, the process is often referred to as secondary steelmaking.
Iron ore can also be directly reduced in solid state using reducing gasses (CO and H_2) derived from natural gas (CH_4) to produce "sponge iron" in the Direct Reduced Iron process. This can then be used to charge the EAF. The two reducing gasses, carbon monoxide and hydrogen, contribute to the reduction process in roughly equal amounts, resulting in respective emissions of CO_2 and H_2O. This illustrates one of the potential transition pathways to carbon neutral steelmaking, 100% hydrogen reduction using hydrogen from the electrolysis of water using 100% renewables [9].

Table 1. Steel making routes

(a) Blast Furnace (BF/BOF)	**(b) Direct Reduced Iron (DRI)**	**(c) Electric Arc furnace (EAF)**
		
Iron ore + coke + others= Pig Iron Pig Iron + scrap (10-30%) + oxygen = Steel $Fe_2O_3(s) + 3CO(s) \rightarrow 2Fe(l) + 3CO_2(g)$	Iron ore+ natural gas = Sponge Iron Sponge Iron + EAF = Steel $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$ $Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$	Scrap/sponge iron + electricity = Steel
Source of CO_2e:	Source of CO_2e:	Source of CO_2e:
Coke as reductant and electricity	CH_4 as reductant and electricity	Electricity

As demonstrated steel is a highly circular and recyclable material. In fact, recycling and reuse are already implemented in the production model. End of life (EOL) recycling rates for steel have been estimated at between 70-90%. This value is one of the highest end-of-life recycling rates among all industrial materials [5]. However, even though most scrap steel arisings are captured and recycled or reused, steel demand is three times higher than the supply of scrap available. Consequently, there will continue to be a need for primary steelmaking to balance supply with demand and this explains why technologies as hydrogen DRI are quite promising.
Making one tonne of crude primary steel with the BF/BOF method takes on average, 1400 kg of iron ore, 800 kg of coal, 300 kg of limestone, and 120 kg of recycled steel. At the same time, for every tonne of endlessly recyclable steel, made at an integrated steelwork, there are 600kg of valuable co-products produced, for example, 400kg of blast furnace slag, which has many different

applications, notably as a cement replacement to reduce the carbon footprint of concrete manufacture. The process is more complex than the simple schematization made and there are many variables that contribute to the carbon footprint of primary production.

Globally around 1200 mt of iron is produced annually in the Blast Furnace (BF) while around 100 mt of iron is made by Direct Reduction (DRI) [6]. According to World Steel [6], in 2020 the world crude steel production was estimated at around 1877.5 million tons, of which was 73.2% BOF and 26.3% EAF. However, if we look to Europe, 139.2 million tons were produced, 57.6% via BOF and 42.4% with EAF. Regarding products in construction, cladding, decking, hollow sections, and plates are almost entirely BF-BOF, whereas reinforcement, open sections and sheet piling are manufactured using either BF-BOF or scrap-EAF.

To understand the order of magnitude of the emissions associated with the various processes, the [A1-A3] embodied carbon factor (ECF), or cradle to gate LCA, will be mainly used in this work.

For steel produced via the BF-BOF route there are approximately 2500 kg of CO_2e emissions per tonne of steel [7]. The EAF can be used to produce steel from DRI (DRI-EAF route), 100% scrap steel (scrap-EAF route/secondary steel making), or a mixture of both. Steel produced though the scrap-EAF process has an [A1-A3] ECF of approximately 500 kgCO_2e/t, while steel produce from DRI-EAF route emits approximately half that of BF-BOF, 1225 kgCO_2e/t [8]. These emissions values can have a variable range, depending on the efficiency of the production process, the technology used, the quantity of scrap, the electricity supply (fossil or renewable), among others; therefore, they must be considered as indicative. For specific processes and products, and manufacturers, the values indicated in a manufacturers' EPD will be more reliable.

2.2 Decarbonization of the steel productions and challenges

As presented in

Table 1, different steel production methods have different sources of emissions and therefore require completely different technological efforts and decarbonization strategies to reach emission reduction targets. EAF steel is already relatively low in carbon. When the feedstock is 100% scrap, the main source of emissions are those indirect emissions due to electricity generation. Over time, as the proportion of renewable electricity in the grid mix increases, the impacts of scrap-EAF steel will reduce.

Different strategies are needed for the primary steelmaking journey toward carbon neutral steel. Among these, green hydrogen can be used to completely replace the use of natural gas in DRI-EAF manufacture (see equation in

Table **1**) bringing the process close to carbon neutrality. Green hydrogen can only be produced with clean energy and the infrastructure to support this shift is not yet ready, however, the steel industry is already moving in this direction [8].

The existing DRI-EAF plant at ArcelorMittal Hamburg will see the first industrial scale production and use of Direct Reduced Iron (DRI) using 100% hydrogen.

The process of reducing iron ore with hydrogen will first be tested using grey hydrogen generated from gas separation. The aim is to achieve H_2 with a purity of more than 97% from the waste gas of the existing plant, using a process known as ‘pressure swing absorption’. This will allow the development of technological solutions at industrial scale to reduce iron ore with hydrogen in the absence of carbon, and to better understand how that product performs downstream in the EAF.

Another possibility, implemented by ArcelorMittal, to decarbonize primary steel making is the Smart Carbon route. This has the potential not only to provide carbon-neutral steel, but also carbon-neutral cement and carbon-neutral biomaterials, more details can be found in [8]. Briefly, fossil carbon in the blast furnace will be displaced initially with circular carbon from waste streams, and the resulting carbon emissions captured for reuse and/or storage. This process has the potential to be carbon negative, and the flexibility to use green hydrogen as it becomes available. To summarise, the strategies being implemented for the decarbonisation of the steel supply chain are based on five major millstones: (i) Steelmaking transformation, from coal to natural gas as a precursor to green hydrogen DRI; (ii) Energy transformation (including green hydrogen, circular forms of carbon and carbon capture usage and storage technologies); (iii) Increased use of scrap; (iv) Sourcing clean electricity; and (v) Offsetting residual emissions.

2.3 Low carbon steel

Many manufacturers have developed low carbon alternatives to their products and processes. An example is the XCarb® umbrella brand, which brings together all of ArcelorMittal's reduced, low and zero-carbon products and steelmaking activities, as well as wider initiatives and green innovation projects, into a single effort focused on achieving demonstrable progress towards carbon neutral steel. The XCarb® recycled and renewably produced (RRP) steel products have a CO_2 footprint as low as 0.33 tonne per tonne of finished steel [10]. All the electricity needed to transform scrap into steel in the EAF comes from renewable sources such as solar and wind power. In this way, by supporting the transition through investment in renewables, the decarbonization of several sectors is combined and accelerated.

For blast furnace produced steel the transition is more complex and involves a broad range of initiatives to reduce carbon emissions. These initiatives range from Smart Carbon technologies, such as Torero and Carbalyst®, to capturing hydrogen-rich waste gases from the steelmaking process and injecting them into the blast furnace to reduce the use of coal [8].

All together, these efforts have resulted in considerable CO_2 savings, which have been aggregated, independently verified, and converted into XCarb® green steel certificates (GSC). The certificates can be used to account for, and report, a reduction in Scope 3 carbon emissions in accordance with the Greenhouse Gas Protocol Corporate Accounting and Reporting Standard [11]. To estimate the value of a green steel certificates, the CO_2 savings from investment projects is calculated by studying the CO_2 impact of different consumables in the blast furnace (for example, when coal is replaced with an alternative reductant). Then the total CO_2 savings are aggregated at company level, independently verified, and converted into a volume of XCarb® green steel certificates (GSC). The calculation uses a coefficient which represents the average Scope 1, 2, and 3 CO_2 intensity of blast furnace-based steelmaking. The calculated volume of XCarb® GSC is expected to grow over the years with the ever-increasing implementation of decarbonisation technologies.

3 ADDRESSING CARBON EMISSION IN CONSTRUCTIONS

Although it is well known that the impact of the construction sector, on the global share of emissions is high, the source of these emissions is often unclear. Fig.4 shows the repartition in percent of the GWP over the lifetime of a prototype building. The highest impact on the emissions is given by the operational carbon (energy consumption), followed by construction materials and their production processes. If this data is spread over the life of a structure (Fig.5), three main "impacts" can be recognized: one constant over the life of the structure (B6) and two peaks, one at time zero (erection time [A1-A3]) due to materials, transport, and construction (eventually commissioning) and one at year 25-30 for renovation/replacement. The constant emissions over the lifetime of the structure are given by the user phase or operational carbon (module B6 of the LCA) while the impact at time 0 is called upfront embodied carbon and is linked to construction materials. Even if the energy impact seems to be predominant today, this impact can be reduced by designing energy efficient buildings with well-designed insulation, efficient HVAC, photovoltaic roofing, etc. Additionally, as the energy supply shifts to renewables, one can assume that this impact will decrease over the next 30 years. Briefly, energy efficiency and renewables drastically reduce operational carbon. On the contrary, the material impact (at time zero and for replacement) remains unchanged and over time will be the major source of CO_2 emissions.

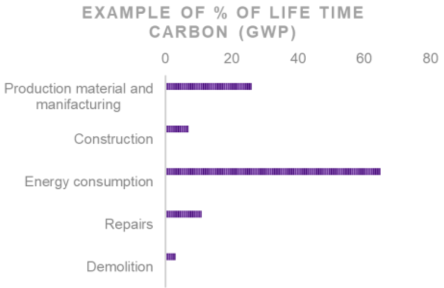


Fig. 4. Percentage of GWP in a building lifetime

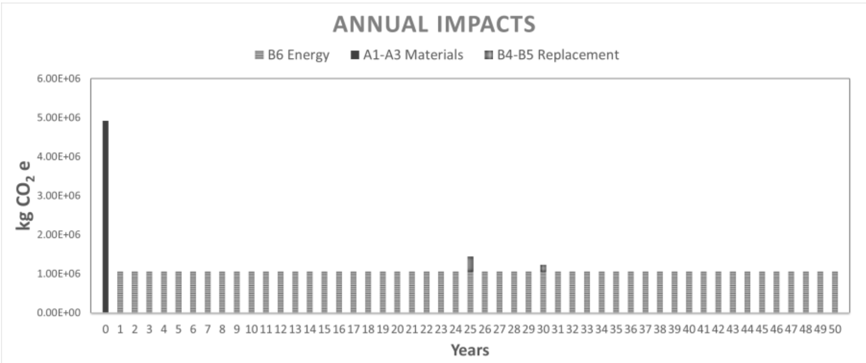


Fig. 5. Example of an LCA for office building Steligence® ArcelorMittal

An important point for designers is to understand how the carbon emission in buildings and construction can be reduced. It is often difficult to select the most appropriate approach. Should the focus be on lean design, or on material sourcing and selection, is the outcome the same if the analysis is Cradle to Gate [A1-A3] or Cradle to Cradle (all stages included) and how should different solutions and materials be compared? The answers are not straight forward and often the solution is not obvious. Designers should be able to compare in a simple but coherent way different solutions and environmental impacts, with the aim of choosing the most appropriate for their project.

3.1 Build with less embodied carbon: the shift toward a circular model

There is an urgency to reduce the emission of materials and construction, especially because a building built today will face many changes in the coming 50 years. Reducing emission also means refurbishment instead of building, design using a life cycle approach, minimizing upfront embodied carbon (lean construction, low carbon materials, low carbon process, etc.), but also thinking about end of life. This last point is crucial in modern design, buildings must be flexible, reduce the embodied carbon for renovation and maintenance, adaption and reconversion of spaces, circularity of materials, including demountability, etc. The approach to sustainable design and life cycle thinking is a complex process and involves all the actors of the construction process, producers, and their engagement in decarbonization, investor, designer, and construction companies. Many authors and studies are devoted to the reduction of impacts, as for example, the concept of 5R's [12], which is a way to decrease the quantity of material used and simultaneously decrease the amount of waste. The 5R's being refuse, reduce, reuse, repurpose, and recycle. According to the 5 R's, four actions should be taken, if possible, prior to 'recycling': refuse, reduce, reuse and repurpose. Reusing and reducing means using less in our daily life and it is even more impactful in the construction sector.

It is well known that *approximately 75% of modern steels have been developed in the past 20 years.* In fact, *if the Eiffel Tower were to be rebuilt today, with the new steel types, it could be built with one-third of the steel that was originally used*. This is true not only in construction but in all the sectors where steel is a key material, *modern cars are built with new steels that are stronger and up to 35% lighter than in the past* [14].

Over the past decades, technology, knowledge, and research have led to a more efficient use and exploitation of steel and materials in general. In a nutshell, this means that the first rule to impact less on the environment, and therefore emit less CO_2, is to use is to "use less stuff". Engineers must rethink the usual way of building; refurbish instead of building from scratch, reduce the amount of material used, use the right material in the right place, use low carbon material, when possible, build having in mind end of life (EoL) and beyond (what will happen to the building after is service life?). This translates, in terms of design procedure, to using appropriate loads, design for least weight, avoid oversizing of elements, manage deflection and then reviewing all of this through the lenses of cost and carbon impacts. More holistically, flexibility and end of life are an old-new way to approach construction. Flexibility in design and space allows for better utilisation of the building potential and can be realized using long spans to create clear spaces that can easily accommodate change of use, allowing for demountable solutions, which allow possible reuse of elements and ensuring a life of the structure far behind the service life. A project and its impacts must always be analysed using a life cycle approach, otherwise there is a risk of missing all the benefits that some sustainable choices bring to the design. For example, the benefits of reducing the weight of structural elements does not only bring a direct benefit (less material = less CO_2) but also many indirect benefits. Among these, less impact due to transportation of materials (therefore less CO_2 from transport and less cost), less weight in the foundations (therefore less material, less excavations, lower cost in construction), lower impact of the construction site (in terms of duration, size, and cost), etc. This simple example explains how without considering the whole picture (LCA) it is not possible to make informed choices and compare solutions or alternatives in terms of sustainability. A project and its impacts must always be analysed using a whole life cycle approach, this is the principle on which the LCA approach is based.

3.2 Reducing embodied carbon of beam elements

Embodied carbon is important through the entire design process. To calculate it, the quantity of material is multiplied by carbon factor (in $kgCO_2$ per kg of material), as shown below:

$$\text{Embodied carbon (EC)} = \text{quantity} \times \text{carbon factor} \quad (1)$$

The carbon factor varies for the different LCA modules. The quantities, especially in early-stage evaluation or feasibility study, might be approximate. However, it is still a good way to assess impacts [7]. In this work, only emissions covering the production processes [A1-A3] (cradle to gate) are considered for the comparison of five alternative column solutions of a tall building. The column type (CT) elements compared are subjected to the same design assumptions, same length

(4m) and, although it is a theoretical exercise, the methodology can be used for different cases and structural solutions. The column types compared, are as follows:

- CT1: Circular reinforced concrete Φ 850 c40/50
- CT2: Circular steel hollow section 508/30
- CT3: Open welded profile (400 x 287)
- CT4: Hot-rolled profile (HD 400 x 287- Histar®)
- CT5: Hot-rolled & low carbon steel profile (HD 400 x 287- XCarb® recycled and renewably produced)

To estimate the value of equation (1), embodied carbon factors (ECF) from relevant EPD can be used or other equivalent sources. Attention must be paid in the calculation because the same materials, from different manufacturers, can have different environmental impacts. For example, the A1-A3 factor for structural steel section varies from 2.45 (British steel EPD) to 0.33 (ArcelorMittal XCarb® recycled and renewably produced EPD for sections and merchant bars). In Table 2 the EPD used in this work are reported with the ECF for [A1-A3], which, when multiplied by the material quantity gives an estimate of the embodied carbon.

Table 2. Used EPD and values

EPD	Producer/publisher	Units	ECF [A1-A3]
Concrete [13]	ICEv3-|C40/50-100% OPC	tCO_2e/m^3	0.42
Reinforcing steel bar	ArcelorMittal/IBU	tCO_2e/t	1.23
Tubular	ArcelorMittal/IBU	tCO_2e/t	2.27
Steel plate	ArcelorMittal/IBU	tCO_2e/t	2.6
Steel profile	ArcelorMittal/IBU	tCO_2e/t	0.524
Low carbon (XCarb®)	ArcelorMittal/IBU	tCO_2e/t	0.333

For example, for CT1 the calculation according to (1) accounting for the contribution of the concrete and the steel rebars is as follows:

$$EC_{concrete} + EC_{RBars} = 0.42\ tCO_2e/m3 \cdot 0.57\ m^2 + 0.135\ t/m \cdot 1.23\ t\ CO_2e/t = \mathbf{405}\ kgCO_2e/m \quad (2)$$

While for CT4, a hot rolled steel profile with high strength steel S460 (HISTAR®), the embodied carbon is as follows:

$$EC = 0.287\ kg/m \cdot 0.524\ t\ CO_2e/t\ steel = \mathbf{151}\ kgCO_2e/m \quad (3)$$

To make comparison easy, the embodied carbon in this case is expressed in kg per m run of column. Quantities can be representative of the functional unit considered, however, when confronting different functional units, the coherence of results must be ensured. All the inputs and the results for the analysed cases are reported in Table 3.

Table 3. EC Results

Case #	CT1	CT2	CT3	CT4	CT5
Dimensions	Φ 850	CHS 508/ 30	400 x 287	HD 400 x 287	HD 400 x 287
Material	Concrete/Rebars	S355	S460	S460 Histar®	S460 XCarb®
Quantity	$0.57m^2$/135 kg/m	354 kg/m	287 kg/m	287 kg/m	287 kg/m
EC	405 $kgCO_2e/m$	807 $kgCO_2e/m$	746 $kgCO_2e/m$	151 $kgCO_2e/m$	95 $kgCO_2e/m$

In the reference project, the initial studied solutions were CT1 and CT2 (BF/BOF production) with an associated embodied carbon of 405 $kgCO_2e/m$ and 807 $kgCO_2e/m$. However, to optimize the design, an open rolled profile in high-strength steel was proposed (CT4), which led to a considerable reduction in weight and dimensions and to a reduction of 80% in embodied carbon compared to CT2. To optimize further, an alternative low carbon material is added (case CT5) and a total reduction of 651 kgCO_2e/m (87%) can be obtained. For comparative purposes also CT1 and CT3 (welded profile) are presented in the Table 3.

4 CONCLUSIONS

This work provides a brief overview of the pathways that are being rolled out to decarbonize steelmaking, additionally the impact of the construction sector on global emissions is examined and discussed. The main purpose of the work is to provide easy to use tools to help designers reduce the embodied carbon in their projects and how to effectively compare different solutions in terms of sustainability. A project or a solution must always be analysed using a life cycle approach, the usual way of conceiving a project must change accordingly: if possible do not build but adapt (renovate); reduce the amount of material used; use the right material in the right place; select low carbon alternatives when possible; build for end of life and beyond and with flexible, clear spaces that are easy to convert, employ demountable solutions using circular materials.
Using life cycle thinking and specifying low carbon alternatives can reduce the carbon footprint of the built environment and help to meet sustainability targets. Low carbon alternatives, such as XCarb®, can help reduce the footprint of construction, and this reduction can be even greater if accompanied by the efficient lean design of high-performance buildings.

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KEYWORDS

Embodied carbon, XCarb®, Circular economy, Steel structures, Climate Emergency, decarbonisation, low carbon steel, decarbonization, low carbon building